A Science Framework for Connecticut River Watershed Sustainability

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Introduction

This document outlines a research framework for water resource managers and land-use planners in the four-state Connecticut River Watershed (CRW). It specifically focuses on developing the decision-support tools and data needed by managers in the watershed.

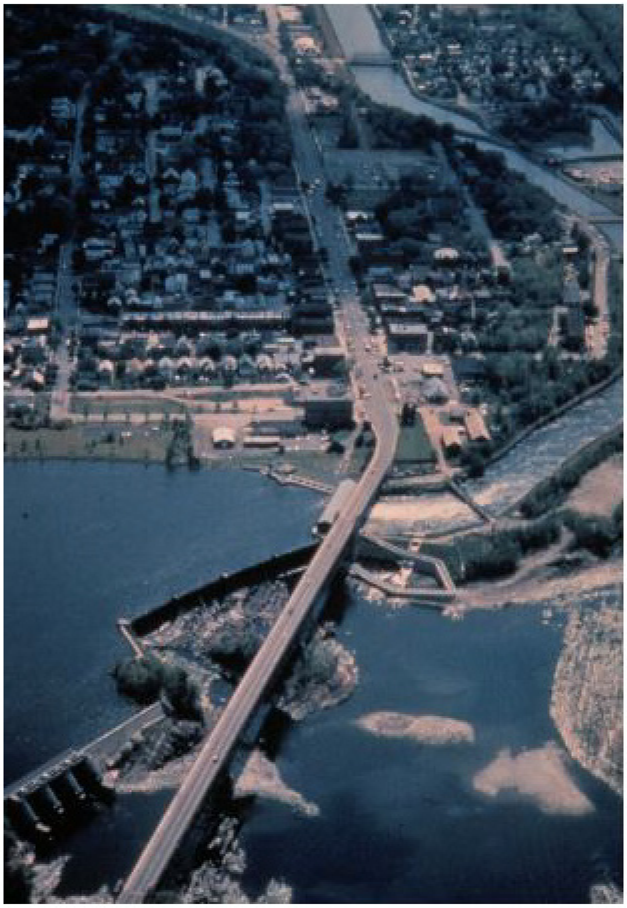
The purpose of the Science Framework is to identify critical research issues and information required to better equip managers to make decisions on desirable changes in the CRW.

This Science Framework is the result of a cooperative project between the U.S. Geological Survey (USGS), the University of Massachusetts at Amherst (UMass-Amherst), and the U.S. Fish and Wildlife Service (FWS). The cooperative project was guided by a Science Steering Committee (SC) and included several focus groups, a 70-person workshop in September 2004, and an open collaborative process by which the workshop outcomes were synthesized, written up, and then progressively refined through peer review. This document is the product of that collaborative process.

The following steps summarize the process of developing the Science Framework:

- In May 2003, senior leadership from USGS and FWS developed an action plan for a Joint Venture Project.
- A Science Steering Committee (SC) for the project was formed in July 2003
- Two Focus Groups were held in January 2004 (each one day long) at the Great Falls Discovery Center in Turners Falls, MA.
- From the discussions at these two Focus Groups, the SC identified 3 thematic areas around which to structure the Science Framework: Development, Dams, and Restoration/Design
- The SC then organized a two-day Science Framework Development Workshop held on September 21-22, 2004 at the FWS Regional Office in Hadley, MA.
- The workshop outcomes were synthesized by the SC into a 1st Draft Framework and sent out to approximately 80 people for review and feedback (October – November 2004)
- The two-month feedback period (December 2004 – February 2005) led to approximately 20 responses from management agencies and workshop invitees.

Connecticut River at West Lebanon, NH. Photo by B.B. Greenbie from the Connecticut River Watershed Council Archives.



Dam, power, canal, and town of Turners Falls, MA. Photo by U.S. Fish and Wildlife Service.

- Comments from this first round of review was incorporated into a 2nd Draft Science Framework document, which was sent to 12 targeted experts for detailed peer review in April 2005.
- Responses from peer reviewers were incorporated into this Final Framework document in May 2005.

A Working Definition of Sustainability

Many people have noted that the concept of 'sustainability' is difficult to define. However, the fact that resource managers, business leaders and academic researchers regularly use the term in spite of its elusiveness suggests that people nonetheless find it to be a useful and valuable 'container' for concisely encapsulating a set of ideas. In our Focus Groups and Science Framework meeting, we adopted the following as an interim definition until basin stakeholders and other participants in the initiative develop a more basin-specific definition of their own:

> The term 'sustainability' encompasses a certain set of long-term goals to maintain healthy ecosystems and the human communities that depend on them; it focuses particularly on how people maintain or restore the composition, structure, and function of natural and modified ecosystems to meet the needs of current and future generations. It is based on a collaboratively developed vision of desired future conditions that integrates ecological, socioeconomic, and institutional components, applied within a geographic framework defined primarily by natural ecological boundaries. (adapted from Meffe et al, 2003)

The boundaries of the four-state watershed provide the geographic framework for this initiative, and the idea of integrating ecological, socioeconomic and institutional perspectives provides the broad intellectual framework. To state it somewhat differently, if the question is '*Who or what is being sustained?*', the four-part answer includes the <u>people</u> who live and work within the watershed, natural populations of certain <u>plants and animals</u>, the use of <u>water and other resources</u> and <u>effective management processes</u> necessary to make decisions and maintain a balance between people, biota and resources.

Goals and Rationale for Sustainability Research

The Goal: An Alternative Futures WebCenter

It is hard to imagine what life will be like in the Connecticut River Watershed in 2050. The midreach of the watershed from Northhampton, Mass. to White River Junction, Vt. has been identified as the next major growth area in New England. What will happen to the flow of water when a million more people in the watershed withdraw surface and groundwater for their everyday needs? How will plants and animals be affected by competition for habitat and water? What tools do planners have available to achieve a sustainable balance between human and ecological communities?

To achieve this idealized balance, people need information about the Connecticut River Watershed from one centralized access point. The information needs to be easily accessed, distributed in easy to use formats, and portable to tools that model impacts of different land-use schemes and community designs that includes cutting edge design such as gray water and green roofs. Users want to examine alternative scenarios, trying to make the best possible decisions for their time and getting best value for their investment.

As a first step to creating an alternatives future webcenter, the USGS will build a web portal to basic land and water databases and information holdings. The web portal will include numerous USGS datasets and The Nature Conservancy's ecoregion datasets. By virtue of the interactive nature of the web portal, there will be links between the electronic version of the Connecticut River Atlas under construction by the Connecticut River Joint Commissions (CRJC) and the USGS Connecticut River Watershed Atlas. Over time other regional atlases and many data layers will be included. Information will be delivered in a GIS environment for customization in map view. Tools for modeling will be explored, developed, and added when they are fully functional. At some time in the near future, there will be an intelligent information center about the Connecticut River Watershed for a wide range of people living and working in the watershed.

Why Study the Connecticut River Watershed?

- Land-use change in New England could dramatically alter the character of the landscape, with large implications for natural resources and ecosystem services. The CRW is an ideal study site for land-use change on account of:
  - the gradient of human pressure that increases from the north (relatively undeveloped) to south (significantly modified by human presence),
  - a long history of native forests being converted to agricultural lands and later returning back to forest, and
  - the complex institutional arrangements that arise from four states and almost 400 towns sharing the watershed.
- The watershed is the largest in the New England region.
- The Silvio O. Conte National Fish and Wildlife Refuge presents a unique opportunity to examine interaction of people and their environment.
- There is a long history of research in the CRW region.
- Many active and long-standing institutional partnerships exist, although there is room for better coordination.

Why Focus on Sustainability?

- With the New England tradition of 'Home rule', there is presently no formal mechanism for regional-level assessment. Since no institutions are responsible for looking at the big picture, multiple small decisions can easily be made at the local level that will have significant cumulative effects on the integrity of the region's ecosystem services (water, biodiversity, etc).
- Because there are four states and multiple agencies involved, there are significant institutional obstacles to sustainability.
- During the last decade there has been much progress in sustainability science and policy that can be beneficially applied and improved upon in the CRW.

Science Issues and Themes

In this section, 14 primary scientific issues are identified that relate to the sustainability of the Connecticut River Watershed. These science topics were all identified by participants at the September 2004 workshop. Part of the purpose of this science framework is to foster an ongoing discussion about the research needs in the watershed and how applied research will address management concerns. These concerns include development permits, the operation, maintenance, and removal of dams, and landscape impact issues (restoration vs. construction).

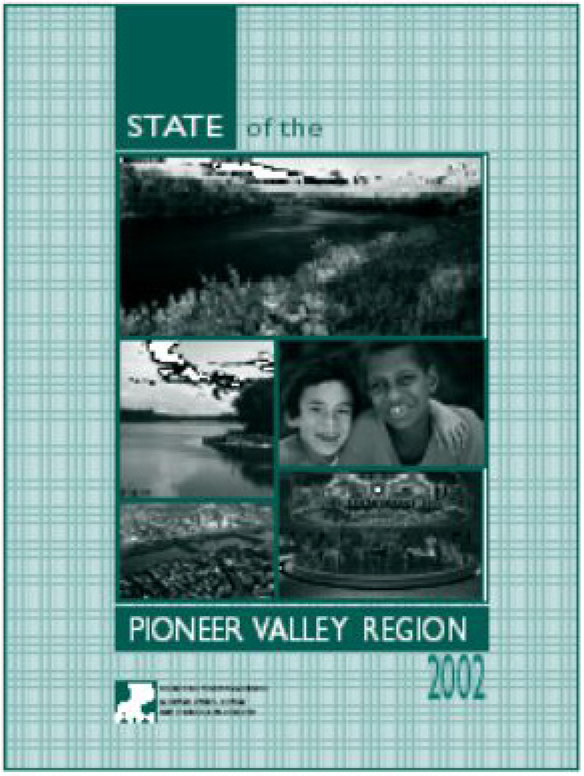
The 14 science issues are grouped together into three primary questions intended to address the overall condition of the watershed. Within each of the three questions, there is a brief explanation of the desired outcome followed by a set of science topics. The significance of each topic is outlined, and specific recommendations for required research are provided.

Where Are We Now?

Issues listed in this first category address the current state of the watershed. In 1952, Yale University developed a 40 page 'State of the Watershed' atlas, and in the early 1980s a similar product was produced by Connecticut River Watershed Council (CRWC) to provide a 30 year update. Since then however, there has been no systematic basin-wide assessment of the overall condition of the watershed. This section identifies major science issues that need to be investigated to answer this question.

Water Budgets and Allocation

The 4-state Connecticut River watershed supplies water to several major urban centers (Boston, Worcester, Springfield and Hartford), numerous small towns, and many rural residents (through groundwater). Several major tributaries of the CRW have been identified by state agencies as 'hydrologically stressed basins' including the Farmington Basin and portions of the Deerfield Basin, (Mass. Water Resources Commission, 2001). In many parts of Massachusetts and Connecticut, summer water use is rapidly increasing, primarily due to increased lawn and landscape irrigation. This reduces the amount of water flowing in rivers and streams, often causing severe stress on aquatic habitats. In New Hampshire, concerns about the management of the state's groundwater resources have mounted during the past few years following a severe drought



Cover of the strategic planning report of the Pioneer Valley Planning Commission, Springfield, MA.

in 2001 and significant new commercial groundwater withdrawals being proposed in southern New Hampshire. These concerns led to increasing support for better management of the state's groundwater resources and more stringent controls over large commercial groundwater withdrawals.

In Connecticut, a Water Planning Council comprised of four state agencies with responsibility for water policy has been meeting for several years to develop policies to address the growing concern about equitable allocation of water. The basis of this work is a plan that includes a wide variety of stakeholders and bases decisions on scientifically-defensible information. This process requires a good database of existing withdrawals and discharges, their location, and the cumulative effects of these and any planned diversions.

Workshop participants repeatedly identified water allocation as a highly relevant science question/need with important implications for water policy. In addition, water budgets could serve as a foundational tool for alternative futures modeling. Research under this theme may include developing sub-basin models, system description and operations, flow impacts from dam operation or removal, and effects on fish migration.

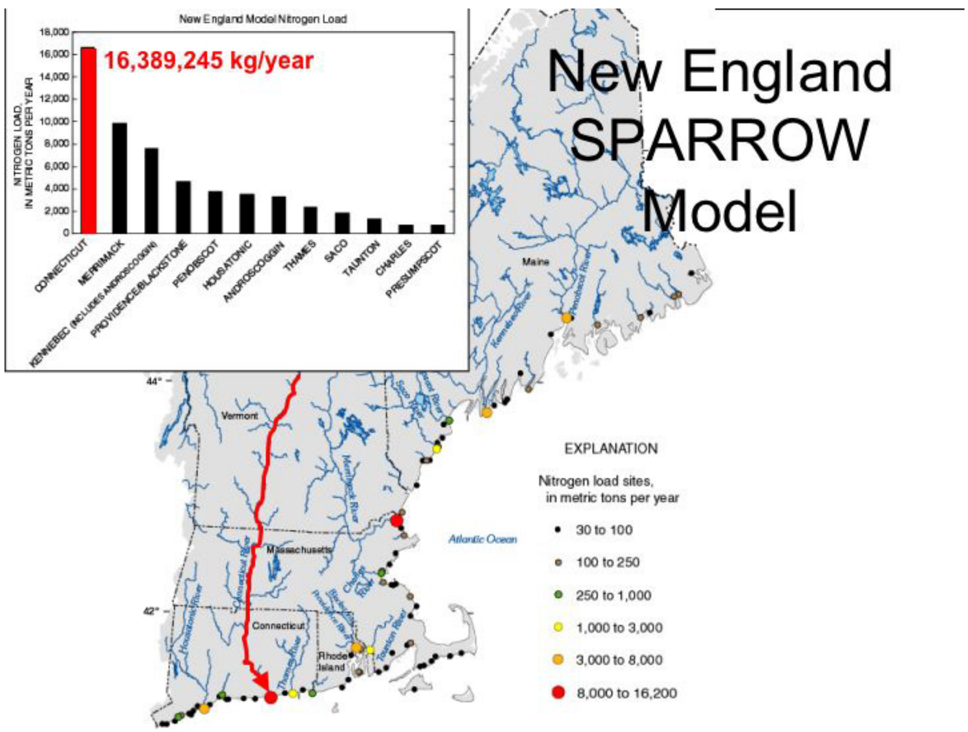
Water Quality Issues

Water quality in streams and aquifers is important because of the implications to human and aquatic ecosystem health and because of the significant costs associated with subsequent clean-up and remediation should water-quality degradation occur. Decisions involving land and water management, conservation, and regulation all have an impact on the quality of water in the CRW. Excessive nitrogen and phosphorus concentrations are common in rivers and lakes throughout New England and more than 30% of lakes in New England were classified by State and Federal agencies as eutrophic in 2000 (EPA, 2000). Although these nutrients are essential for healthy plant and animal life, elevated concentrations lead to a variety of problems. Nutrient concentrations are typically higher and pesticides are more likely to be found in streams draining urban and agricultural areas than in streams draining forested areas.

Total Maximum Daily Load (TMDL) strategies, Combined Sewer Overflow (CSO) impact analysis, agriculture best management practices and sediment transport are all important issues that relate to land use policy and water quality. Management of nitrogen loads to Long Island Sound is a current water-quality management priority by USEPA and the states in the region – the CRW is a major source of nitrogen to the Long Island Sound. A TMDL for nitrogen contributions to Long Island Sound currently exists in the states of Connecticut and New York. Additional load allocations in the upper states in the CRW (MA, NH and VT) are planned in the next 3-5 years. USGS is currently working with the New England Interstate Water Pollution Control Commission and USEPA to monitor nitrogen loads and in-stream loss and to model nitrogen sources and transport (through the New England SPARROW water quality model) in the CRW for future allocation decisions. There remains a need for a long-term nutrient monitoring strategy for the CRW in light of future nutrient control actions and to develop predictive tools for future nutrient loads based on land use changes. The problem of combined sewer overflows has been somewhat reduced relative to the late 1980s, when 134 CSOs were identified in the Massachusetts part of the watershed below Holyoke Dam, 31 of which discharged even in dry weather (Mass. Div. of Water Pollution Control, 1988). The problem was not completely resolved however, and in 2001 there were still 78 identified CSOs in lower Massachusetts, although only 3 of these overflowed in dry weather. Research is needed to address cost-effective ways for towns to eliminate CSOs, since without large federal appropriations it is unlikely that towns can afford to do so.

Pollution from PCBs (polychlorinated biphenyls) has led to the entire length of the Connecticut River in Massachusetts not meeting water quality standards (based on fish consumption advisories). However, the Mass. Department of Public Health fish consumption advisory is based on 15 year old data. In addition, contamination of fish by mercury is a regional concern as fish consumption advisories are in place by all states in the CRW.

Extreme low flow conditions in small headwater trout stream sustained by ground water.



New England SPARROW Model projected load to Long Island Sound. USGS data.

The quality of groundwater supplies is another issue that participants identified in the watershed. Understanding the natural variations in ground water quality for constituents such as arsenic, as well as anthropogenic contaminants such as volatile organic compounds like methyl tertiary-butyl ether (MTBE) and pesticides in the CRW is an on-going need.

Because of the gradient of development pressures throughout the watershed, and the wide variation in sub-watersheds, communities, population density, and differing stormwater controls, there are excellent scientific opportunities for understanding the relationship between land use, management practices (such as road de-icing salts or stream buffers) and water quality within the CRW. In summary, at our workshop,

Littleville Army Corps of Engineers Dam, Westfield River, MA. Photo by New England Army Corps of Engineers.

water quality came up repeatedly and is consistently a top priority for the public.

Situation Assessment of Dams and Culverts

The first dam on the Connecticut River was constructed in 1798 in Montague, MA. Dams proliferated in the watershed over the next century and a half, and current estimates vary of the total number of dams in the watershed. TNC estimates that there 850 small dams in the CRW, the vast majority of which are privately owned (80-85%). The National Inventory of Dams uses a combination of height and impoundment size as a cutoff for inclusion. The Commonwealth of Massachusetts monitors 3,000 dams that are more than 6ft high and/or impound more than 15 acre-ft of water. Some states use 15 ft at a cutoff for 'small' dams.

The Silvio O. Conte Refuge Environmental Impact Statement (USFWS 1995) states that there are 'approximately 980' dams in the watershed, including 16 mainstem dams that act as functional obstructions in the aquatic environment. This total of 980 dams apparently includes both 'large' and 'small' dams. All dams degrade under the pressures of time, gravity and flowing water and these dams typically have a life expectancy of around 50 years, but many of the smallest structures are over a century old. Without continual maintenance and repair, many of these old dams are likely to fail. Based on state dam removal task force data, more than 60% of these dams present a significant threat to public safety.

In addition to inventories of dams, it is now recognized that other structures can impact river continuity and the free flow of aquatic and terrestrial resources. Road crossings involving culverts and bridge construction can impact the aquatic and associated riparian habitat. Resource agencies are now evaluating the number and impact of these structures. In Massachusetts for example, their Riverways Program has a program dealing with river continuity and the movement of fish and animals. This includes both an inventory and evaluation component leading to restoration actions if needed (see the Massachusetts Riverways Continuity web page at www.mass.gov/dfwele/river/rivercontinuity.htm).

The primary inventories of dams in the CRW at present are the National Inventory of Dams (maintained by USACE) and databases maintained by the four states' Dam Safety offices (which are CT: Dam Safety Section, Inland Water Resources Division (Dept of Environmental Management); MA: Dam Safety Office (Dept of Environmental Management), NH: Dam Bureau, Division of Water (Dept of Environmental Services); VT: Dam Safety Section (Dept of Environmental Conservation). The definitions of what constitutes a 'dam' vary from state to state, and the hazard category definitions differ among the four states too. An updated and harmonized inventory of the existing dams in the watershed is needed in order to develop a comprehensive picture of the current fragmented state of the aquatic system. The inventory needs to address two fundamental questions: a) which dams in the watershed serve a valued economic or community function, and which do not; and b) which dams most impede important fisheries and/or other ecosystem functions. It should include information on the degree to which individual dams can actually be 'managed' (versus dams which are 'merely there' and cannot be operated in any way), as well as the dams' location, integrity and functionality, sediment levels, impact on existing systems, fish passage, ownership, responsibility, and connectivity. An inventory of contaminants and sediments sequestered behind dams is also important information needed to assess the dam's function and use. Many Federal agencies including the Army Corps of Engineers, the U.S. Geological Survey, the U.S. Fish and Wildlife Service, and the Environmental Protection Agency have an interest in the topic of dams, and would be obvious partners.

Biogeochemical Cycling

Chemical cycling and the transport and fate of contaminants are important issues to understand in order to predict the long-term environmental changes in the watershed. Research on chemical cycling includes understanding the sources and pathways of nitrogen and phosphorus in the watershed system (see 4.2 above for the science theme of water quality), but also needs to deal with the issue of contaminants, particularly contaminated sediments. The case of the Hudson River is now well known, where several hundred thousand tons of polychlorinated biphenyls (PCBs) were discharged into the river by two manufacturing plants prior to the 1970s. These PCBs then bioaccumulated in fish and other aquatic organisms that were subsequently consumed by people, and for a long time all fishing was banned on the Upper Hudson River for public health reasons. The extent of contaminants in the Connecticut River is not very well known, particularly contaminated sediments

Springtime shad fishing below the Holyoke Dam in Massachusetts. Photo by U.S. Geological Survey

Forest products. Photo by U.S. Department of Agriculture's University of Massachuesetts Extension Service.

stored behind dam walls. If dams are to be removed, either naturally or intentionally, there is a need to quantify these contaminants, any historical or modern sources of contamination, and the downstream effects. In Vermont and New Hampshire, an EPA sediment study in 2000 found contaminants from parking lot and road runoff at a number of locations as far north as Pittsburg village, and traces of copper from the mines high in the Waits and Ompompanoosuc watersheds of Vermont. At some sites, the contaminants were in levels high enough to threaten aquatic life. In 1999, USGS conducted studies on the Otter River and Millers River in Massachusetts and found that PCB concentration in water throughout the main stems of the Millers and Otter Rivers exceeded the U.S. Environmental Protection Agency's water-quality criterion. In addition to PCBs, there is a strong mercury deposition gradient across the Connecticut River watershed, and many managers have concerns about mercury levels in the watershed.

The most costly aspect of dam removal is the question of sediment quality and the long-term fate of sediments and their associated contaminants in the watershed. The quantity and quality of sediment trapped behind dams, especially the identification and concentration of contaminants it might contain, are key issues that must be addressed in environmental reviews prior to dam removal. Managers also need models that can predict sediment transport and deposition in downstream areas after dam removal. These types of models clearly need to interface with hydrologic models, since sediment deposition is strongly related to flow conditions. There are opportunities to expand our understanding of nitrogen source and fate through isotropic tracer injections at sites like the USGS Sleepers River watershed. More research is also needed on the biological aspects of contaminants, particularly studies of fish tissues, since PCBs and endocrine disruptors accumulate in these tissues.

Socio-economic Issues and Benefits

Although socio-economic issues were specifically identified in the Science Framework Development workshop and participant evaluations as an important dimension of this initiative, there was widespread agreement among workshop participants these issues were underdeveloped relative to the other themes listed in this document. The current Strategic Plans for the U.S. Department of Interior and the FWS Fisheries Program specifically identify public use and other socio-economic benefits as important criteria in priority setting. In addition, the 2001 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation indicated that direct expenditures on these natural resource-related activities alone were over $108 billion that year in the United States. However, managers seldom have such economic information for these and other resource benefits, especially at the local and regional level.

One example of the kind of research that is needed under this science theme is a study on the economic benefits of a 14 mile reach of the Farmington River in western Connecticut. The study was conducted in 2003, and found that recreational river use generates an estimated annual economic impact of $3.63 million for the five towns nearest the river stretch studied. These benefits included higher property values (proximity to the Farmington River accounts for approximately 8% of the value of nearby residential land) and more diversified local economies.

A second example comes from Massachusetts, where 70% of the forested land is privately owned. To be more specific, approximately 64% of forested land in the Commonwealth of Massachusetts is owned by over 212,000 private families and individuals. The remaining 36% of forested land is owned publicly (30%) and commercially (6%). In western Massachusetts (i.e., in the Mass. part of the CRW), 77% of forest lands are privately owned. The Massachusetts Woodlands Cooperative (MWC) was formed in 2003 by a group of forest landowners for the purpose of managing their lands, and cooperatively processing and marketing timber products that could be certified as 'sustainably produced' by the Forest Stewardship Council (For more details, see *www.masswoodlands.coop*). The goal of MWC is to use long-term forest management and local value-adding to forest products in order to create a sustained flow of forest benefits including timber, wildlife, clean water, aesthetics, and recreation. Currently, the MWC has 31 members and 4,400 acres, and is producing high quality flooring from mid- to low-quality trees. The membership goal is 125 members and 20,000 acres of land in western Massachusetts over the next 3 years. Enterprises such as WMC enhance forest management, produce a sustainable stream of economic benefits, and offer opportunities for research into effective methods of accomplishing environmental and socio-economic goals simultaneously. In landscapes dominated by small, private, non-industrial forest ownership, a vast array of important ecosystem services and public benefits are provided free of charge to the general public. The future trajectory followed by private non-industrial forest owners will ultimately determine much of the sustainability of this landscape. However, processes of parcelization, fragmentation, and conversion to residential land are reducing the number of forested acres, increasing the number of owners, and complicating the future of these landscapes. Research that addresses these themes will make a valuable contribution to fostering CRW sustainability.

Social and economic considerations are an important element of sustainable ecosystem management, and are included as such in the interim definition of sustainability adopted for our Focus Groups and workshop. Although we recognize that this issue is currently underdeveloped within our initiative, we welcome partnerships with other groups that will help to strengthen the initiative in this area.

A 'State of the Watershed' Atlas

The first watershed wide atlas was produced over 50 years, and although CRJC and Dartmouth College are producing an atlas for the upper watershed (to be released in 2006) there is no systematic basin-wide assessment of the overall condition of the watershed. The current state of the watershed (including the issues listed above in points 4.1 to 4.6) should ideally be summarized on a regular basis and in a consistent way in order to evaluate progress in all four basin states. In the same way that economists use indicators such as the unemployment rate to measure progress in the economy, increasing use is being made of environmental and social indicators to chart the progress made on restoring ecosystems. For a portion of the CRW, the Pioneer Valley Planning Commission (PVPC) has produced since 1999 an annual or bi-annual 'State of the Environment' report (covering economic and ecological indicators for a 26-town region in western Massachusetts), but this covers less than 10% of the total basin. The Long Island Sound Study, begun in 1985, identified a number of crucial problems in the Sound and has a set of indicators for evaluating the health of the Sound over the last 20 years. Two approaches that participants recommended for the CRW would be the development of a set of 'State of the Watershed' indicators (together with a regular process for measuring and reporting them), and a systematic attempt to summarize (in detailed atlas format) the current state of the watershed. Building on the CRJC Upper Basin Atlas project, an excellent opportunity exists to extend the project to MA and CT. If this product were to be completed for the entire watershed, it would provide an extremely valuable set of summary answers to the question "where are we now", and could become the basis of a regular 'Indicators & the State of the Region' process like that in the Great Lakes region, the Chesapeake Bay watershed, and various urban centers such as Seattle WA, Boulder CO, and Cambridge MA.

Where Are We Going?

The second category of issues focuses attention on defining the future desired condition of the watershed. Similar projects in Chesapeake Bay, central Arizona and the Pacific Northwest have successfully made connections between present-day land- and water-use decisions and the future state of the system at a time-scale of several decades. By clarifying the kind of future conditions that stakeholders, policy-makers and agency managers hope to see in the Connecticut River basin over the next four to five decades, scientists will be in a position to develop forecasting tools that allow decision-makers to see some of the longer term ecological and social consequences of their decisions and thus improve long-term management.

Developing a Shared Public Vision

The question 'What are we trying to restore the system TO?' kept coming up as a major unresolved issue at the science workshop. There is a clear need for a stakeholder-involved process for visioning the future and developing a shared idea about the future desired condition, or some kind of 'reference' or 'target' towards which we wish to move the state of the basin. Target conditions would include both socio-economic factors of interest to basin stakeholders (e.g., land-use, energy, transportation, etc) and ecological factors (e.g., flow regime, the size and configuration of stream buffers, river geomorphology, reference fish communities, terrestrial habitat availability etc). The management goal of such a process would be to identify trade-offs and arrive at solutions that sustain public benefits and ecological integrity. For example, in the Penobscot River in Maine, a public vision for the river's future brought about a more balanced outcome that involved removal of one dam inhibiting fish restoration while allowing increased hydropower production at other dams to meet regional energy goals. This task of developing a shared public

Stakeholder workshop on priority science issues. U.S. Fish and Wildlife Service photo.

vision needs to consider how to energize the public, empower them, and connect them with the experts. In addition, the river must be viewed as a long-term societal investment that needs to be managed within its ecological limits.

For the NH and VT portion of the watershed, the CRJC is currently in the process of revising their 1997 *Connecticut River Corridor Management Plan* into a new *Upper Connecticut River Management Plan* that reflects the public's vision, priorities and specific recommendations for the northern part of the river. Over a hundred people are involved in a multi-year discussion in numerous meetings. The focus is primarily on the mainstem, though it also reaches up some of the tributaries and incorporates sub-watershed plans undertaken by state agencies, regional planning commissions and others. Although this process is already well underway in the northern half of the basin, there is no equivalent stakeholder process in the southern half (MA and CT). In November 2006, FWS will begin developing a Comprehensive Management Plan for the Silvio O. Conte National Fish and Wildlife Refuge. This effort will provide another important opportunity to hear from stakeholders about their vision for restoring and sustaining wildlife and related natural resources in the watershed. In addition, other basinwide planning efforts by federal agencies (e.g. EPA, NRCS, ACE), existing commissions (e.g. CRASC), and non-government organizations (e.g. TNC, CRWC) could also provide essential information and/or useful platforms for contributing to a shared public vision for the basin. Though beyond the scope of this research-related initiative, the development of a shared, four-state vision of sustainability will be vital for basin partners to successfully target ecological and social priorities with increasingly scarce management resources (see the discussion in Section 2 on defining sustainability). Proposed institutional and policy analysis under issue 4.14 may also be especially valuable in this regard.

Ecological Flow Prescription

Water management is driven by quantified objectives, such as specified levels of flood protection, generation of hydropower, or reliability of water supplies during drought. Similarly, water-related *ecological objectives* need to be quantitatively defined so that they can be integrated with other water management objectives. Defining such ecosystem flow requirements in the CRW presents many difficult challenges for scientists, since the link between flows and the viability of various species is generally poorly understood. Estimating ecosystem flow requirements will require input from an interdisciplinary group of scientists familiar with the habitat requirements of native biota (i.e., species, communities) and the hydrologic, geomorphic, and biogeochemical processes that influence those habitats and support primary productivity and nutrient cycling. There is a need to compile from the scientific literature what is known about the response of key ecosystem elements (species, or suites of species) to the hydrologic 'signatures' of various river reaches within the watershed. Since this cannot realistically be done for every species, ideally this process would involve selecting assemblages of species and natural communities that are representative of the entire system, since this would provide useful data beyond the specific locations for which it is done.

Once the knowledge about ecological response to flow regime has been synthesized, the next step would be to develop a prescribed 'target annual hydrograph' at various points along the river. When these quantitative targets for ecological flow requirements are implemented, ongoing monitoring, research, and adaptive management will then be needed to investigate scientifically the extent to which this target hydrograph improves and maintains the health of the aquatic system. The Nature Conservancy (TNC) shares a strong interest in the topic of ecological flows and has a great deal of expertise to share through their Sustainable Rivers initiative. This presents a good opportunity for partnership in evaluating the physical (and chemical) flow regimes and their effects on aquatic biodiversity and health. Four natural communities have been suggested for an initial round of literature review and ecological flow determination: native resident fish, diadromous fish, riparian wetlands (including floodplain communities) and native freshwater mussels.

In addition to the need for understanding species flow requirements and for a target annual hydrograph prescription, researchers, managers and policy-makers identified the need for GIS data, and for hydrological models capable of evaluating flow regime effects (see section 4.11 below).

Land Use Change and Terrestrial Habitat

Land use directly impacts environmental health, human quality of life and ecosystem integrity in a number of ways. Research has shown that land use that results in loss of habitat is the number one determinant of loss of biodiversity, more so than climate change, release of nitrogen, biotic change (such as introduction of invasive species), and atmospheric change (Sala et al, 2000). Because the CRW encompasses a large and diverse area, it provides habitat for a significant number of species, including 59 mammals, 250 birds, 22 reptiles and 3,000 plants (USFWS, 1995). The resource managers and planners who attended the workshop listed several concerns related to habitat-loss, particularly issues with wetlands and upland habitat. In Massachusetts, a recent study found that between 1985 and 1999, approximately 40 acres per day of forested, agricultural or open land was 'visibly converted' to developed land (residential, commercial, or industrial) (Mass. Audubon, 2003). The aerial photographic methods used for this assessment do not necessarily show the full extent of development: for example, they are not able to distinguish between intact forest and trees in the rear portion of a developed lot and do not account for subdivision and changes in land ownership, which can lead to additional fragmentation. To address these limitations, in addition to the 'visible conversion' methods (based on the aerial photographs), the study also reviewed a statewide tax assessor's land parcel database, and found that from a land ownership and total parcel perspective, land use changes due to development actually impacted 78 acres per day between 1985 and 1999, almost <u>double</u> the visible impact.

New Hampshire is the fastest growing state in New England, increasing 11.4% in population between the 1990 and 2000 censuses. In a recent survey of residents in 12 New Hampshire towns, respondents' top answer to the question of why they like to live in their town was to do with open space, historical character or natural beauty (Ducey et al, 2004). When asked what the biggest issue was facing their towns, the issue of urban growth and sprawl was mentioned by more respondents than any other issue. These statistics from Massachusetts and New Hampshire show the magnitude of the land-use problem, and its importance to New England residents.

At our workshop, managers and decision-makers identified a need to understand the relative ecological importance of certain areas as they make parcel-by-parcel or town-planning decisions with limited resources. There is not consistent land-use data available across the four states of the CRW: the land classification systems used by Massachusetts and Connecticut are not fully compatible, and GIS land-use data in Vermont is not available for many towns. In addition to these relatively straightforward data needs, managers at the workshop also identified the need for models that can help them understand the broader-scale off-site impacts of these local-scale decisions in order to assess tradeoffs between land-use change and terrestrial habitat.

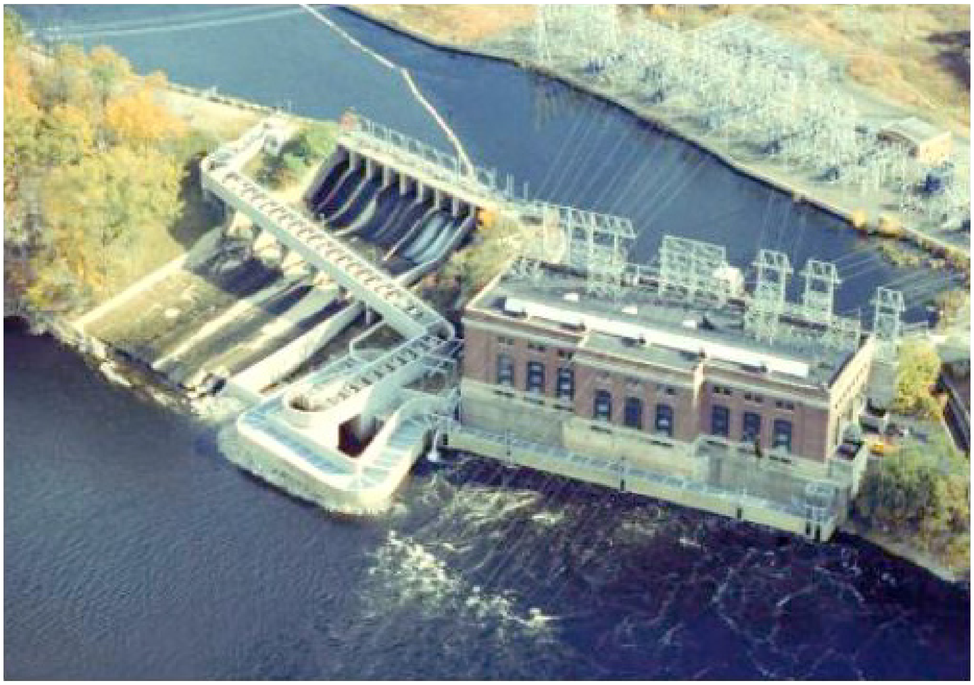
How Will We Get There?

The third category of science issues identifies some of the approaches and tools that would be required to address the second group of questions (Where are we going?). Since dams are one of the most obvious ways in which the watershed processes have been modified by human activity, two of the issues listed relate to dams (of which there are over 900 in the watershed). Most of the issues listed in sections 4.1 to 4.12 span multiple scientific disciplines, and because no centralized system exists yet for sharing various datasets, there is a strong need to develop tools for open collaboration among researchers.

Projecting Future Land Use and Population

In the northeast region of the United States, the majority of the land is in private ownership. Over the next 50 years there will be increased pressure on New England landscapes for residential development, while still expecting the watersheds to provide clean water, economic sustainability for growing communities, and habitat for resident plants and animals. Suburban and rural residential development into agricultural and forested areas presents one of the most significant changes in watershed condition. Development is increasingly low-density in character. The presence of existing low-density residential settlement patterns often precludes any increases in density, because of zoning restrictions and availability of infrastructure. Land-use change models can be used by researchers and managers to explore the dynamics and drivers of land-use/land-cover change and to inform policy decisions affecting these changes. In the New England context, town planning boards are beginning to develop masterplans for their communities that spell out a future vision for land-use in their communities. In Massachusetts, the Executive Office of Environmental Affairs undertook a build-out analysis that shows the maximum development possible in a given community and allows community officials and residents to see what their future may look like based on current local zoning. This analysis has not been done for towns in the other three states.

Exercises such as these are critical for stakeholders and managers to <u>see</u> what the future might look like in the next 25 to 40 years given current trends. Landscape change models are needed that can be used to develop scenarios of future landscape condition. GIS and mapping tools are needed to help visualize these changes. In addition to landscape change, this science theme includes the need for simulation models that can link landscape change to changes in hydrology, water-quality conditions, sediment transport, ecosystem changes and the influence of invasives. These tools would provide a visual aid to resource managers. Part of this involves an inventory of zoning regulations and current land use by town. GIS mapping should be expanded, and attached to flow models such as has been done in New York State, with the goal of providing



Cabot Station, Turners Falls, MA and Cabot Fish Ladder, USGS photo.

a build-out analysis to show the influence of urbanization and development on hydrology.

Integrated Dam Management and Operation

The Army Corps of Engineers (ACE) operates 14 flood control dams on tributaries within the Connecticut River Basin, collectively controlling almost 1/6 of the flow in the basin. Since 2001, following recommendations of the FWS, the ACE has been operating these dams largely run-of-river (with the exception of flood control activities). In addition to the tributary dams, there are 16 mainstem dams used for hydropower (owned by USGen, Northeast Utilities, Simpson Paper and two other private owners). These hydropower dams are collectively capable of generating nearly 600 megawatts of power which is used throughout the basin. The management of water levels and operational modes of these dams is obviously a major determinant of river flows, and ideally the watershed ought to be viewed and managed as a single river system. While the hydropower industry has simulation models for power generation, the various owners operate their dams with little overall coordination, and without taking ecological flow needs into consideration. At present, there is not a complete understanding of who all the stakeholders are. The inventory of existing dams outlined above in section 4.3 would be a useful product not only for this purpose, but also for providing information on which dams have operational flexibility.

Ideally, a unified hydrological model of the full mainstem and major tributaries is needed in order to address this theme of dam operation. Although the development of a complete hydrologic model for the entire basin will be a major undertaking, one possible intermediate goal to begin addressing this science and management theme is the development of a scaleable modeling framework for mainstem reaches and suites of tributaries. The primary goal of such a model would be to explore what the implications would be for the hydropower industry (both in generation capacity and economic implications) of adjusting the hydrograph to meet ecological needs. Because the ACE dams on the tributaries are already generally operated run-of-river (apart from flood control activities), and probably do not have sufficient storage available to offset mainstem hydropower flows, it is not obvious how much would be gained from modeling of the effects of tributary dam operation on the mainstem hydrograph. Furthermore, the ACE dams can only be operated in accordance with their authorized purposes (i.e., flood control), and in the past the Connecticut Flood Control Commission has intensely opposed any flow augmentation that could detract from flood control storage.

The scientific and research issues related to simulating the effects of dam operation scenarios are fairly straightforward, even for a basin the size and complexity of the CRW. The primary consideration for this task is probably the cost of such an exercise relative to the benefits it would provide. This depends on whether the model (and its results) would ever actually be used to optimize river flow management for multiple uses of the river. This implies the need for some kind of multiple-criteria decision making framework that can evaluate on an ‘apples-to-apples’ basis the relative costs and benefits of various operating rules for a wide range of purposes (e.g. flood control, hydropower, recreation, water supply, waste assimilation, ecological needs, etc.). In other words, advancing this science priority not only requires some review of the primary modeling options, but also the data requirements of each model, the pros and cons of various approaches, and a well-defined process to determine appropriate scales of modeling. Far more importantly, an analysis is required of the institutional opportunities and constraints (regulatory, socio-economic and political – see 4.14 below) to using integrated dam management and operation for optimizing multiple-purpose objectives, and the assembly of a 'constituency' who would support the model development process. Although these are probably more time-consuming tasks than moving directly to modeling options, data collection and model development details, in the medium to long term they are likely to be far more important to the overall goals of this sustainability initiative.

Assessing Benefits, Goods and Services Provided by Dams

Many of the dams within the CRW currently require maintenance and some may be candidates for removal. Using the dam situation assessment as a starting point (see 4.3 above), it would be valuable to know the extent to which each dam affects the flow regime and contributes to habitat fragmentation, and to identify which of them are likely to become maintenance hazards in the next few decades. There are presently no decision-support tools tailored for comparative evaluation of these various factors for CRW dams. At the same time, it is also important to assess and quantify the societal benefits that accrue from functioning dams; these issues are often not easy to quantify.

To frame this issue more broadly, whenever restoration projects of various types are proposed, planners and decision-makers generally need answers to two key questions: a) what benefits to people and ecosystems can reasonably be expected from the proposed project? and b) what will be the cost of both of action *and* inaction. For example, removing a specific dam could have various economic, aesthetic and flood-control costs in addition to providing a range of beneficial ecological services; on the other hand, *not* removing the dam might involve public safety risks. At present, decision-support tools for assessing the goods and services provided by various restoration projects are limited by the challenge of accurately quantifying the value of such services. Research into these issues is therefore needed in order to better predict the outcomes of maintaining the current dam infrastructure, knowing which dams provide the greatest benefits to society, and which are the most damaging to ecosystem integrity and health.

Data Sharing System

Scientific research has much in common with the open-source approach to developing computer operating systems and software. Its essence is the sharing of intellectual property: theories, data, models etc. Over the last decade, the Internet has made data-sharing far easier than in the past. There are now many data repositories that provide the free sharing of data collected from past research projects. (See for example, a GIS watershed data repository at *http://www.mvp.usace.army.mil/gis/*; data from many federal agencies can be accessed at GeoSpatial One Stop Portal *http://www.geo-data.gov/gos*; and for an example from the social sciences, see *http://www.icpsr.umich.edu/org*) Systems are needed to facilitate the sharing of information (between scientists of different disciplines, and between community and scientists). A major part of this effort will involve the collection, unification, software management, displaying and visualizing the information in easy-to-understand format. Obviously, before information can be shared, it has to be available, and there are many cases where information has not yet been digitized.

Data types that could be usefully shared via some kind of metadata system include: Geographic Information System (GIS) data layers, such as road networks, landcover maps, satellite images, political boundaries, etc; non-geographic data such as spreadsheets on timber prices over time; citations of relevant publications or reports; and information about a person or organization with a specific research interest or expertise.

Institutional and Policy Analysis

The social sciences offer important perspectives on institutional mechanisms that facilitate the integration, implementation, evaluation and adaptive management of basin-wide sustainability initiatives. Workshop participants suggested, for example, the possibility of developing and examining several draft scenarios for institutional governance arrangements within the watershed based on varying levels of inclusion and participation by the four States. An analysis like this was conducted for the three states of the Chesapeake Bay, and although not all the scenarios put forward were ultimately deemed workable or even acceptable, the intention was for them to open up some doors to creative thinking and for further refinement into working models that may be adopted.

Under the broad heading of this scientific issue would be an analysis of current institutions and ongoing management initiatives within the watershed, and the political feasibility of establishing a basin-wide governor-appointed basin commission to address all aspects of sustainability. Policy analysis is another area for research. Although a myriad of local, state, and federal policies interact at various times to influence land ownership and management, there is a relatively small number of policies which have a direct bearing on land-use, river management and water quality. Local zoning ordinances directly limit the extent to which open space can be and is converted to residential, industrial, and commercial developed land use. No systematic study has reviewed zoning and land use policies in the 394 towns of the watershed, but it is often brought up as information that would be of use to Regional Planning Commissions.

Another example of this would be an analysis of the regulatory, economic, political and social constraints and opportunities of changing the current uncoordinated approach to dam management. The 14 USACE dams in the CRW can only be operated in accordance with their authorized primary purpose of flood control as defined in the Flood Control Act of 1944 (PL 78-534). Only two of the ACE reservoirs (Littleville and Colebrook) in the CRW have supplemental authorization to serve multiple purposes, namely water supply and fishery storage. The Connecticut River Basin Master Water Control Manual last underwent a comprehensive update 23 years ago (the next update is due in FY-07), although the recent Corps implementation of the FWS New England Flow Policy should be considered a significant change to the regulation of Corps dams relative to multi-purpose objectives. The New England Flow Policy, recommended in 2001 by Region 5 of the FWS, addresses Minimum Outflow, Aquatic Base Flows (ABF) and ramping and refill rates. Flood control operations have also incorporated the Minimum Outflow and ABF recommendations of the FWS. It seems very unlikely that any further significant changes to the operation to achieve multi-purpose objectives will be accommodated in the short term. Likewise, the operation rules for hydropower structures are specified in the FERC license for the structure. The FERC relicensing process generally occurs in a 15-year cycle (although some licenses for add-on hydro facilities at Corps dams have a 40-year life), and negotiations for changes in the operating rules to accommodate multiple-use interests, are confined to the process prescribed under the relicensing rules.

At present, the social science aspects of this Science Framework document are recognized as being underdeveloped, and the Science Steering Committee welcomes further input.

Methods, Data, and Collaborative Infrastructure

Imagine that it is 2012 and a new community is on the drawing board in Vermont in the West River watershed. At the same time a public hearing is planned for reviewing a proposal to add several thousand housing units in the Aschuelot River Valley. Do the plans achieve “sustainability?” There are many approaches to understanding the impacts of development. There are the different needs and perspectives of designers of human communities and stewards of ecologic communities. Understanding the Connecticut River watershed as an integrated system of multiple dimensions, including biophysical as well as socio-economical, requires creative interdisciplinary approaches and methods. These include, but are not limited to:

- Geographic Information Systems. All data collected in the watershed include a spatial component, but there is presently no centralized system for assembling, storing, and accessing the many different datasets that pertain to the Connecticut River watershed.
- Data-sharing across disciplines and assembly of datasets. For example, an inventory of certain types of dams combined with a dataset on distribution of invasive aquatic species may help managers to identify high priority areas.
- Visualization tools that give managers and planners the ability to ‘see,’ in a dynamic way, the present and future conditions of the watershed.
- Landscape change simulation models that can explore the ecological and socio-economic consequences of (for example) different zoning policies, forestry practices, population growth, or land-use conversion for water availability, water quality, and biodiversity.

Priorities and Implementation

This document is intended as a science framework rather than a detailed plan, and the 14 research issues listed above are outlined mainly as general topic areas. Specific research projects arising from this initiative will need to be developed through multiple Requests for Proposals, scoping meetings and through the creation of a more detailed science plan and a clearly articulated strategy for implementation. The SC felt however, that even at the level of the broad framework it was still necessary to develop a sense of the relative priority of each science issue. At the September 2004 Science Framework Development workshop therefore, breakout groups were asked to prioritize their top two research issues. From that process, five clear priorities emerged, although not in any obvious order of importance or priority:

- Water budgets/allocations (e.g. basin models, system description and operations, flow impacts associated with dam removal)
- Water quality (e.g.TMDL models, CSO impact analysis, sediment transport, contaminants)
- Ecological Flow Prescription (e.g. required flows to sustain biodiversity, flows associated with target fish communities, flows necessary for fish passage)
- Development of data-sharing systems (e.g.Web-based GIS systems, Watershed Atlas)
- Developing a shared public vision for the watershed

The Steering Committee noted after the workshop that these research issues were also the ones emphasized in all three thematic breakout groups (see Table 1).

Table 1. Science themes and issues as identified by the various workshop breakout groups. Themes in bold print were identified and discussed by groups representing all three of the main topic areas (development, dams, restoration/design).

	Breakout Group Topic Areas		
Science Themes	**Development**	**Dams**	**Restoration/Design**
Where are we now? Present condition			
•Water budgets/allocation	■	■	■
•Water quality issues	■	■	■
•Inventory of dams and barriers		■	
•Biogeochemical cycling, fate/transport		■	■
•Socio-economic issues	■		
•"State of the Watershed" Atlas and Indicators	■	■	
Where are we going? Desired future condition			
•Developing a shared public vision	■	■	■
•Ecological flow prescription	■	■	■
•Land-use and terrestrial habitat	■		
How will we get there? Decision support tools			
•Projecting land use and population	■		
•Integrated dam operation and management		■	■
•Assessing goods and services (dams/restoration)		■	■
•Data sharing systems	■	■	■
•Institutional and policy analysis	■		

Connections With Other Initiatives

The research agenda outlined in this framework document complements and interacts with other initiatives, and builds on a long history of research in the Connecticut River basin. It will draw upon the data and knowledge generated in other programs, wherever possible, by using the rich legacy of monitoring efforts, infrastructure and datasets.

Some of the specific ties and connections to these other programs are listed below in alphabetical order:

Connecticut River Airshed-Watershed Research Consortium

The objective of this group of academic researchers is to study and quantify the long-term fate of pollutants in the Connecticut River Basin. Quantifying the interfacial exchanges of contaminants from one medium to another (air-soil, surface-groundwater, environmental-human) is seen as one of the most scientifically intractable set of problems in the basin. The consortium is presently funded by EPA.

Connecticut River Atlantic Salmon Commission

The Connecticut River Atlantic Salmon Commission (CRASC) provides management guidance on all administrative and biological issues related to the restoration of Atlantic salmon and other anadromous fish species. Established by Congress in 1983 (and reauthorized in 2002 for another 20 years) through the Connecticut River Atlantic Salmon Compact (Public Law 98-138), it is composed of ten Commissioners, representing four State agencies, the public, and two Federal agencies.

Fluvial Geomorphology Assessment (Upper River, VT and NH)

In October 2004, Dr John Field of Field Geology Services conducted a fluvial geomorphological assessment for the CRJC. The assessment covers the 85 mile section of the Connecticut River between Murphy Dam and Canaan Dam. The Caldonia and Essex County Conservation Districts in Vermont have undertaken other recent fluvial geomorphological assessments on the Passumpsuc River and other Connecticut River tributaries.

Long Island Sound Stewardship System (LISS)

The Long Island Sound Study (LISS) is a cooperative effort sponsored by the US Environmental Protection Agency, the state of Connecticut and the state of New York. The LISS involves other federal, state, and local agencies, researchers, user groups, and other concerned organizations and individuals to protect and improve the health of the Sound. In 1994, EPA and the states of Connecticut and New York approved a Comprehensive Conservation and Management Plan for the Sound developed by the LISS. The plan identifies the specific commitments and recommendations for actions to improve water quality, protect habitat and living resources, educate and involve the public, improve the long-term understanding of how to manage the Sound, monitor progress, and redirect management efforts. The top management priority is to eliminate the adverse impacts of hypoxia resulting from human activities. A TMDL has been developed to achieve a 58.5 percent reduction in the total enriched load of nitrogen to Long Island Sound from point and nonpoint sources within the New York and Connecticut portions of the watershed, by 2014. As part of that effort, nitrogen reduction targets were set for atmospheric deposition and watershed management for portions of the Long Island Sound watershed outside of New York and Connecticut. A Connecticut River work group has been established that involves Massachusetts, Vermont, and New Hampshire to develop scientifically-defensible nitrogen load allocations for the CT river basin.

National Water Quality Assessment Program (NAWQA)

The NAWQA Program is assessing the water-quality conditions of more than 50 of the Nation's largest river basins and aquifers, known as Study Units. Collectively, these Study Units cover about one-half of the United States and include sources of drinking water used by about 70 percent of the U.S. population. The study unit #2 includes the basins of the Connecticut River, the Housatonic and the Thames.

New England Invasive Plants Atlas

This project has created a comprehensive web-accessible database of invasive and potentially invasive plants in New England that will be continually updated by a network of professionals and trained volunteers.

The Nature Conservancy: Basin-Wide Eco-Regional Planning

In December 2003, TNC hired a Program Director to begin a new program for the Connecticut River Basin. During 2004, working on a track that parallels the development of this Science Framework document, TNC has developed a strategic eco-regional plan for conservation work within the Connecticut River Basin. The goal of their planning process has been to identify the most important and urgent conservation tasks for the Conservancy to address. This plan includes conventional land acquisition projects, but also brings in a wide range of other conservation strategies including the operation of dams for ecological flows.

Upper Connecticut River Watershed Atlas

The development of a comprehensive Atlas for the NH-VT portion of the watershed is jointly sponsored by the Connecticut River Joint Commissions and Dartmouth College, with Northern Cartographic. The print and interactive web versions of the Atlas are currently under development, and will include extensive maps, graphics, and images. Chapters span over forty topics and include Physical Geography, Water Resources, Ecosystems, Human History, Land Use and Development, Transportation, Energy, and Communication, Governance and Resource Management, Culture and Enjoyment, Watershed Resource Issues. Chapters are presently (2005) under development.

Upper Connecticut River Management Plan

This plan is currently under development by the Connecticut River Joint Commissions and their five bi-state local river subcommittees. The plan is addressing Water Quality and Quantity, Fisheries and Aquatic Habit, Shoreland and Upland Habitat, Recreation, Agriculture and Forestry, Historical and Cultural Resources, Land Cover, Guidance for Development. It will include consideration of in-stream flows, river restoration and dam removal, fluvial geomorphological processes, protection of groundwater supplies, and low impact development principles.

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Names of the science steering committee are **underlined in bold**.

In addition to the steering committee, feedback and review of various draft versions of this science framework have been received from people whose names are in ***italics***.

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Appendix B. List of Acronyms

ACE	US Army Corps of Engineers
CRASC	Connecticut River Atlantic Salmon Commission
CRJC	Connecticut River Joint Commissions
CRW	Connecticut River Watershed
CRWC	Connecticut River Watershed Council
CSO	Combined Sewer Overflows
EPA	Environmental Protection Agency
FWS	US Fish and Wildlife Service
GIS	Geographic Information System
LISS	Long Island Sound Study
MTBE	methyl tertiary-butyl ether
NAWQA	National Water Quality Assessment
NRCS	Natural Resource Conservation Service
PCB	Polychlorinated biphenyl
PVPC	Pioneer Valley Planning Commission
SC	Steering Committee
TMDL	Total Maximum Daily Load
TNC	The Nature Conservancy
USGS	US Geological Survey